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HYDROSTATIC EXTRUSION OF 60MM MORTAR  
TUBES

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Watervliet Arsenal  
Watervliet, New York

October 1974

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ABSTRACT (Continued)

of the increased high temperature strength inherent in the material.

As an adjunct to this project, an estimate was made of the potential savings for hydrostatically extruded gun steel mortar tubes compared to forged tubes. It is estimated that a savings of approximately \$63 per tube would be possible.

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HYDROSTATIC EXTRUSION OF 60MM MORTAR TUBES

Richard S. DeFries



**BENET WEAPONS LABORATORY  
WATERVLIET ARSENAL  
WATERVLIET, N.Y. 12189**

OCTOBER 1974

**TECHNICAL REPORT**

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### Introduction

This project was concerned with the room temperature hydrostatic extrusion of Inconel 718 alloy 60mm XM225E2 mortar tubes, under Contract #DAAF07-72-C-0360 with Battelle, Columbus, Ohio Laboratories and the evaluation of the tubes produced. The evaluation was made to determine the feasibility of the process, mechanical properties imparted to the tubes by the process and any cost savings the process may incur when compared to the conventional method of manufacturing by machining 60mm tubes from forged or conventionally extruded bar stock.

### Evaluation Method

The hydrostatic extrusion process was evaluated in the following manner:

a. Processing parameters:

An in depth study of the processing parameters is presented in the final report<sup>1</sup> submitted to this Arsenal. The optimum extrusion parameters and the costs to hydrostatically extrude 718 alloy 60mm mortar tubes are shown.

b. Visual and Dimensional Check of Tubes:

Dimensional checks were made on the four extruded and aged tubes which were hydrostatically extruded. A metallurgical and/or microscopic investigation of the extruded 718 structure and any surface defects noted on or in the tubes was also conducted.

1. "Production of Inconel 718 Mortar Tubes by Hydrostatic Extrusion" Final Report by Battelle, Columbus Laboratories, April 1973. NWF 74527.

c. Mechanical Property Tests:

One tube was sectioned for longitudinal and transverse tensile and Charpy impact properties. A ten inch long section was cut from the tube for pressure testing.

d. Machining and Cost Analyses:

One tube was finish machined to the 60mm XM225E2 dimensions listed in the prototype, Drawing #WTV-F23990. Cost analyses were obtained for finish machining, in lots of 500 and 1000, Inconel 718 as-extruded and aged tubes (per Drawing #WTV-C22870) and also the cost to finish machine 60mm tubes made by the regular manufacturing methods using forged or conventionally extruded bar stock.

e. Gun Steel Extrusion:

Since, for the immediate future, 60mm mortar tubes will be produced from standard low alloy gun steel, a comparison was made of the cost to produce a hydrostatically extruded tube and a forged tube, considering the subsequent machining costs.

RESULTS AND DISCUSSION

A. Processing Parameters:

The optimum extrusion parameters were developed using sub-size Inconel 718 extrusions (Figure 1) and full size AISI 1018 alloy bar tubes. Both the ID and OD were reduced during extrusion to alleviate a shallow surface tensile tearing problem. Figure 2

shows a Cu plated 1018 partially extruded tube which illustrates the original blank size (left side of picture). Using the parameters and tooling below, Battelle successfully extruded four Inconel 718 alloy 60mm tubes. The parameters used to extrude these tubes were:

Fluid - Castor oil

Lubricant - Cu plate and resin-bonded graphite  $\text{MoS}_2$  coating

Extrusion Ratio:

Inconel 718 - 2.2:1

Steel 1018 - 2.4:1

Extrusion Pressures:

Inconel 718 Breakthrough - 180 - 195 ksi  
Run Out - 150 - 155 ksi

Steel 1018 Breakthrough - 82 - 90 ksi  
Run Out - 76 - 82 ksi

Press Ram Speed - Approximately 5 inches/min.

Billet Dimensions - 3.450 in. OD x 2.650 in. ID x 20.0 in long

Tube Dimensions (Nominal) 2.787 in. OD x 2.363 in. ID x  
approximately 40 in. long

Die Configuration:

Diameter - 2.765 (Pre-stressed diameter)

Approach Angle - 22-1/2° (half angle)

Land Length - 0.2 in.

Manifold Configuration: 2.390 in. tapering to 2.356 in. over 22 in.  
of length (0.0015 in/in.)

The four Inconel 718 tubes were then straightened, heat treated (iced  
at 1150°F for 8 hrs.) and subsequently ID honed at Battelle to complete  
their processing.

### B. Visual and Dimensional Check of Tubes

The Inconel 718 alloy as-extruded and aged 60mm tubes (Figure 3) were checked for ID, OD and wall thickness dimensions, and for concentricity and straightness. The results are shown in Table I. The dimensions of the as-extruded tubes (Figure 4) do not conform to the drawing dimensions shown, but do conform to the contract dimensional range aim shown below:

Length - as specified on the drawing

O.D. - 2.764" dia. (+ .030 - .005) and 125 RMS finish

I.D. - 2.390" dia. (+ .025 - .010) and 64-125 RMS finish

The .020" difference in the OD of Tube No. 1, as compared to the other three tubes, is due to the fact that the OD of this tube was centerless ground after extrusion for cost analysis. The difference in the breech to muzzle ID diameters is due to the 0.0015 in/in taper on the mandrel, and would have been larger if the tubes had not been ID honed. The straightness of about .010 inches was obtained after a straightening and aging cycle; the as-extruded tubes had a straightness, based on dimensional deviation of the center line from a truly straight line, of about .049 inches. All of the above measurements were in close agreement with those dimensions measured by Battelle (Table I, Reference 1).

In the visual examination of the tubes, numerous circumferential hairline cracks about .005" deep, thought to be tensile tears, were noted on the ID surfaces (Figure 5). A photomicrograph of a cross section of these cracks, Figure 6, shows the structure of the extruded and aged 718 alloy tubing and it also shows the shear bands leading to the surface

tears. The 45° angle that the shear bands form with the surface of the tubing has been seen in numerous other cold and hot tearing investigations.<sup>2,3</sup> On the OD, similar but smaller cracks (about .002" deep) were found (Figure 7).

### C. Mechanical Property Tests

One tube was sectioned, as indicated in Figure 8A, for longitudinal and transverse tensile and Charpy-impact properties. Sub-size flat tensile and Charpy bars, Figure 9, were machined from these sections. The results are shown in Tables II - IV.

The 0.1% yield strength of the as-extruded and aged 718 material was about 238 ksi, which is about 80 ksi higher than the standard heat-treated and aged alloy. The transverse 0.1% yield strength was recorded as 40 ksi lower than the longitudinal yield because the bars failed prematurely in the electron beam weld used to fabricate the specimens (Figure 8B). The welded tensile specimen is required to obtain the transverse tensile properties in a thin walled tube. The welded specimen was aged after welding and the area in the center of the one inch long test section was reduced by an amount that should have caused the specimen to fail in the center of the transverse test section. Evidently, the area was not reduced enough to prevent a failure in the welds. Rather than fabricate additional specimens, a section of tubing was hydrostatically tested to determine yield strength.

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2. Pope, Dr. J., "Shear Band Tearing During Hydrostatic Extrusion" unpublished report.
3. Defries, R.S., "Hot Tearing Characteristics of Cast Ingots" unpublished, Allegheny Ludlum Steel Co. Report.

The Charpy impact strengths in Table IV, are shown in actual sub-size values and the calculated standard size value using a correlation relation of 4.5 times the sub-size value, determined from previous testing of 81mm mortar tubes.<sup>4</sup> This transverse value of 13.5 ft-lbs at -40°F is very high for the yield strength experienced.

A 10 inch section was cut from the extruded tube, Figure 8, and pressure tested (Figure 10). The results (Table III) showed that the 0.1% yield strength was about 225 ksi prior to yielding when the seals gave out. Therefore, all types of testing indicate that the extruded and aged 718 material has a 0.1% yield strength in both the longitudinal and transverse directions of about 225 to 242 ksi.

#### D. Machining and Cost Analysis:

##### 1. Inconel 718

One as-extruded and aged tube was finish machined to the dimensions stated on the current 60mm machined tube drawing (FTV-F23990), with the exception that the OD fin diameter was 2.760 instead of 3.350 inches. The modified fin configuration can be seen on the right side of the tube shown in Figure 11. The fin size was limited because of the size of the extrusion. However, with the use of high temperature alloys, it is expected that the fin may not be required to cool the tube since the 718 alloy retains its high strength (120 ksi) at high (1000-1400°F) temperatures. The modified fins were machined to reduce the weight of the tube. The finish machined tube weighed nine pounds.

An estimated cost analysis on hydrostatically extruded and machined Inconel 718 60mm XM225E2 mortar tubes was made with the assistance of the Arsenal Operations Directorate, and compared to

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4. DeFries, R.S., unpublished data.

those tubes machined from forged blanks. This cost analysis was based on the production of 500 and 1000 units. Battelle's extrusion costs<sup>1</sup>, in-house current material costs and in-house machining costs were used to determine the cost per 60mm tube for each alloy. The results of this analysis were:

| <u>Number</u> | <u>Inconel 718<br/>Extruded</u> | <u>Forging</u> |
|---------------|---------------------------------|----------------|
| 500 units     | \$ 1,783                        | \$2,165        |
| 1000 units    | 1,720                           | 2,110          |

2. Low alloy gun steel

For informational purposes, the costs to produce gun steel tubes from extrusions and from forgings were also estimated. It was assumed that the extrusion costs of the gun steel would be the same as those for the Inconel 718 and that two tubes would be produced from each extrusion. The costs are shown below:

| <u>Number</u> | <u>Gun Steel<br/>Extruded</u> | <u>Forging</u> |
|---------------|-------------------------------|----------------|
| 500 units     | \$ 367                        | \$ 385         |
| 1000 units    | 292                           | 355            |

1. "Production of Inconel 718 Mortar Tubes by Hydrostatic Extrusion" Final Report by Battelle, Columbus Laboratories, April 1973. WVT 74027.

## CONCLUSIONS

Based on the results obtained, the following conclusions are appropriate:

1. Cold hydrostatic extrusion of Inco 718 alloy 60mm mortar tubes is feasible.
2. The yield strength of the 718 can be increased from 160 ksi to 240 ksi by the extrusion process over forged and heat treated components.
3. The toughness or impact strength of the extruded and aged 718, as estimated from sub-size specimens, is high for the yield strength obtained and comparable with the standard treated material.
4. A cost savings of about \$390 can be realized with hydrostatically extruded 60mm 718 alloy mortar tubes. However, the costs are still higher than tubes produced from gun steel.
5. An estimated cost savings of \$63 per mortar tube can be obtained in gun steel.

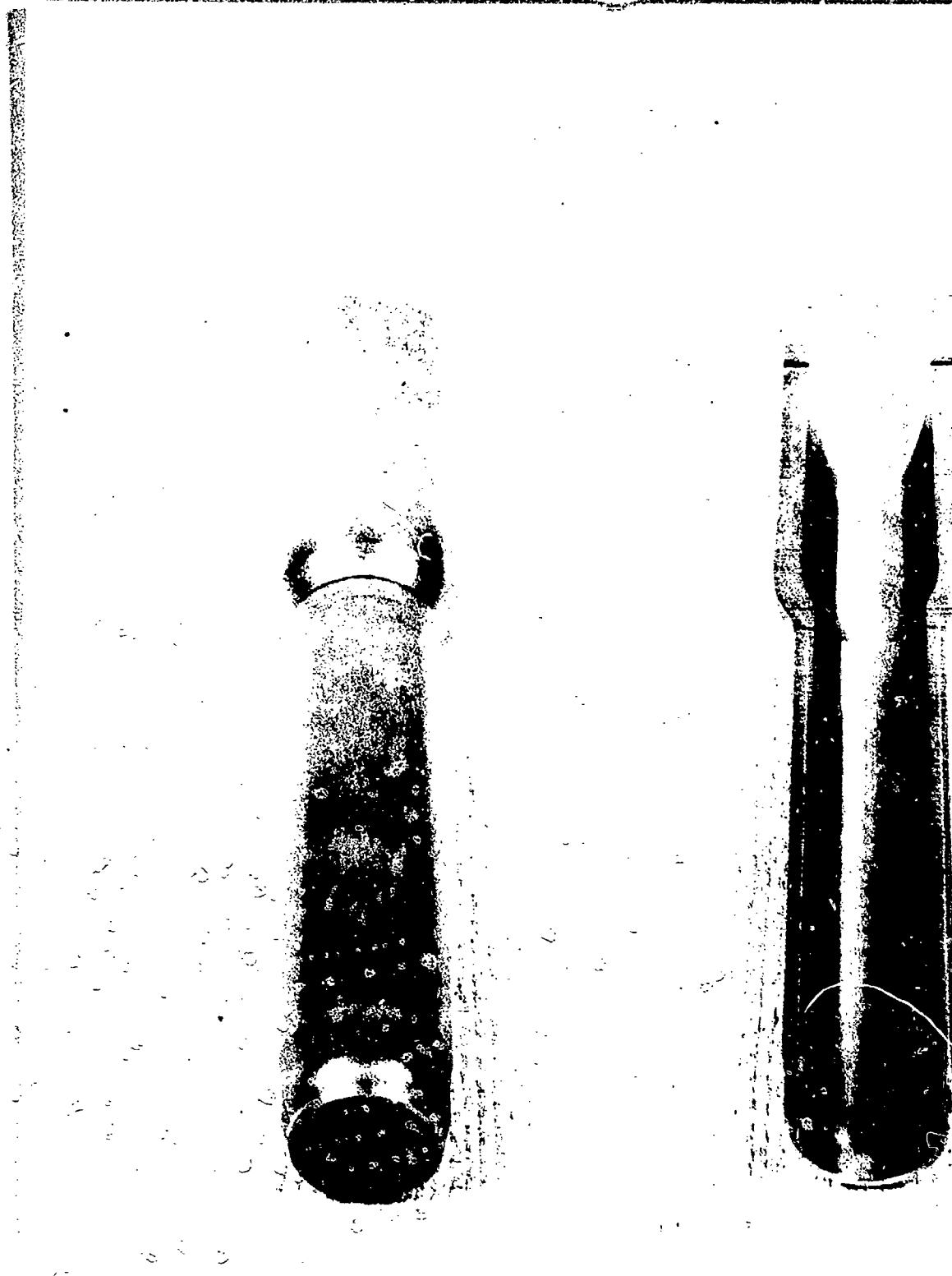


FIGURE 1. SUBSCALE INCONEL ALLOY 718 TUBE EXTRUDED IN THIS PROGRAM SHOWING EXCELLENT ID SURFACE FINISH DUE TO INCORPORATING AN ID REDUCTION DURING EXTRUSION

**COPPER PLATED 1018 ALLOY  
BLANK AND EXTRUDED TUBE**

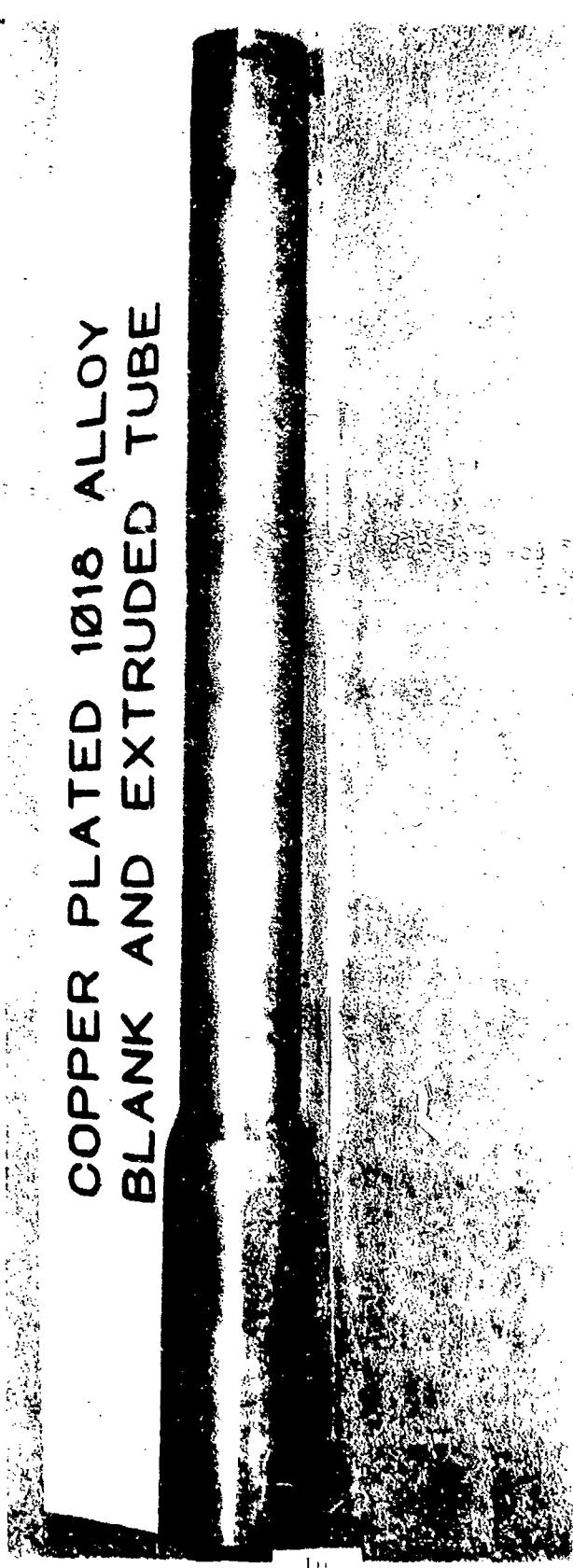


FIGURE 2. Cu Plated AISI 1018 Alloy Blank (left) and Extruded Tube on the right

EXTRUDED AND AGED 718 ALLOY TUBE

Figure 5. As-extruded and aged inconel 718 Alloy tube

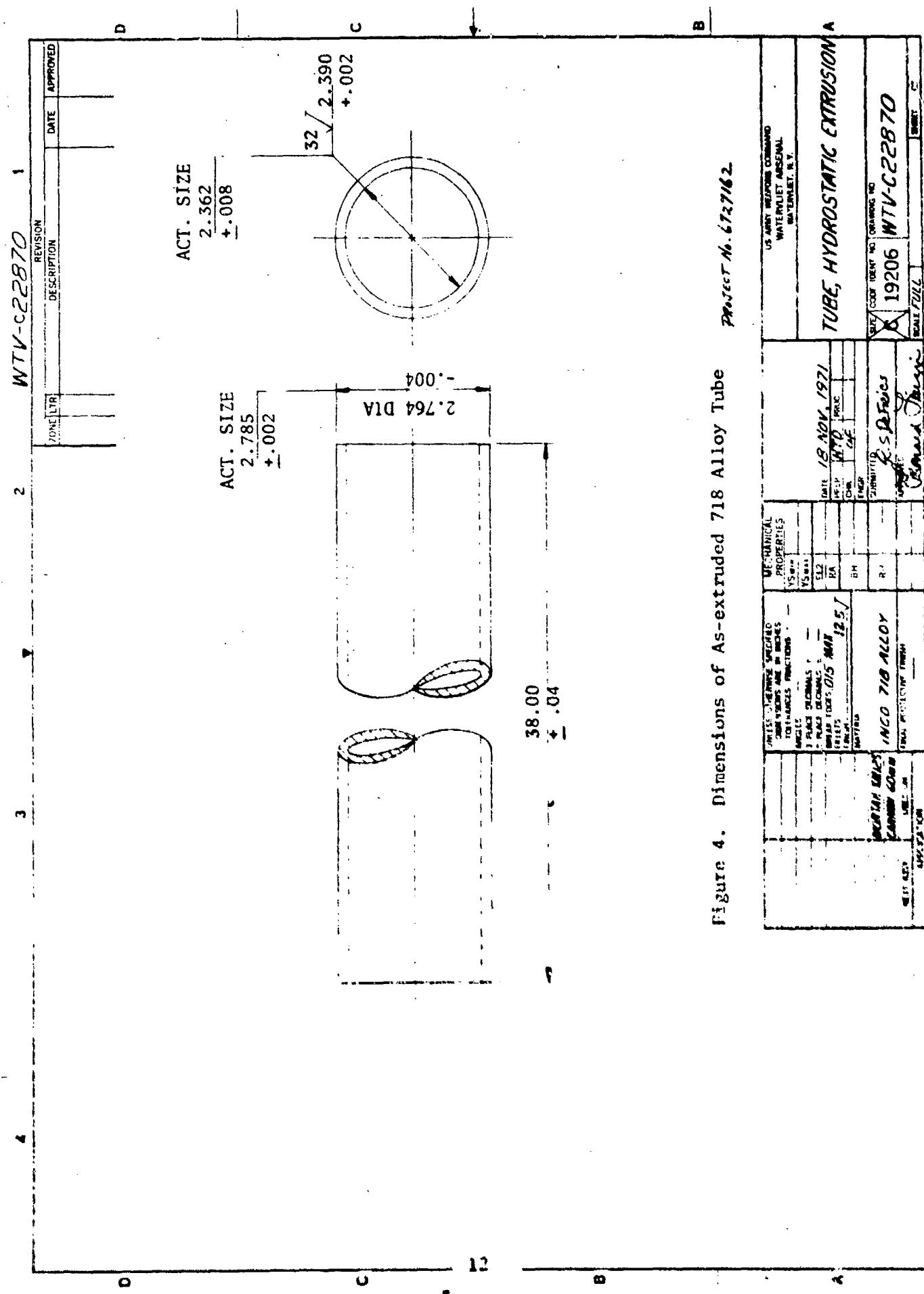
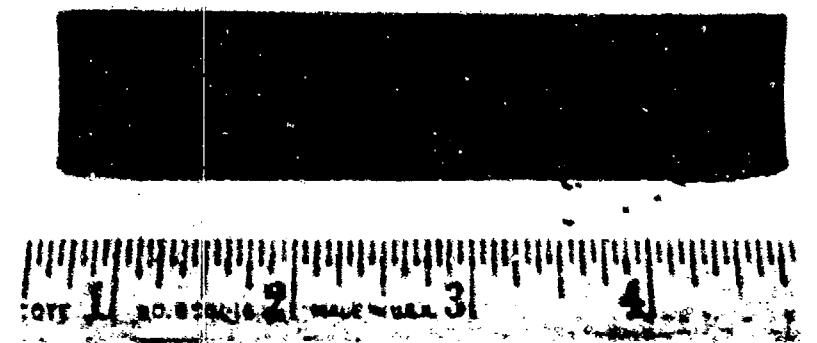


Figure 4. Dimensions of As-extruded 718 Alloy Tube

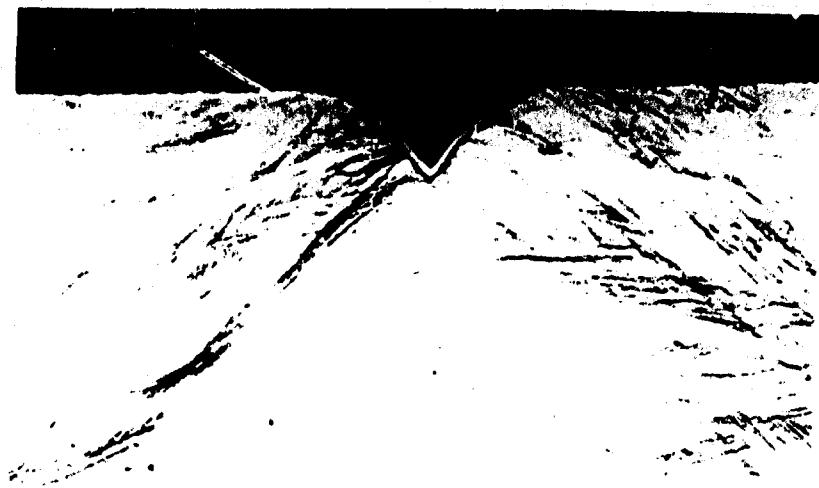


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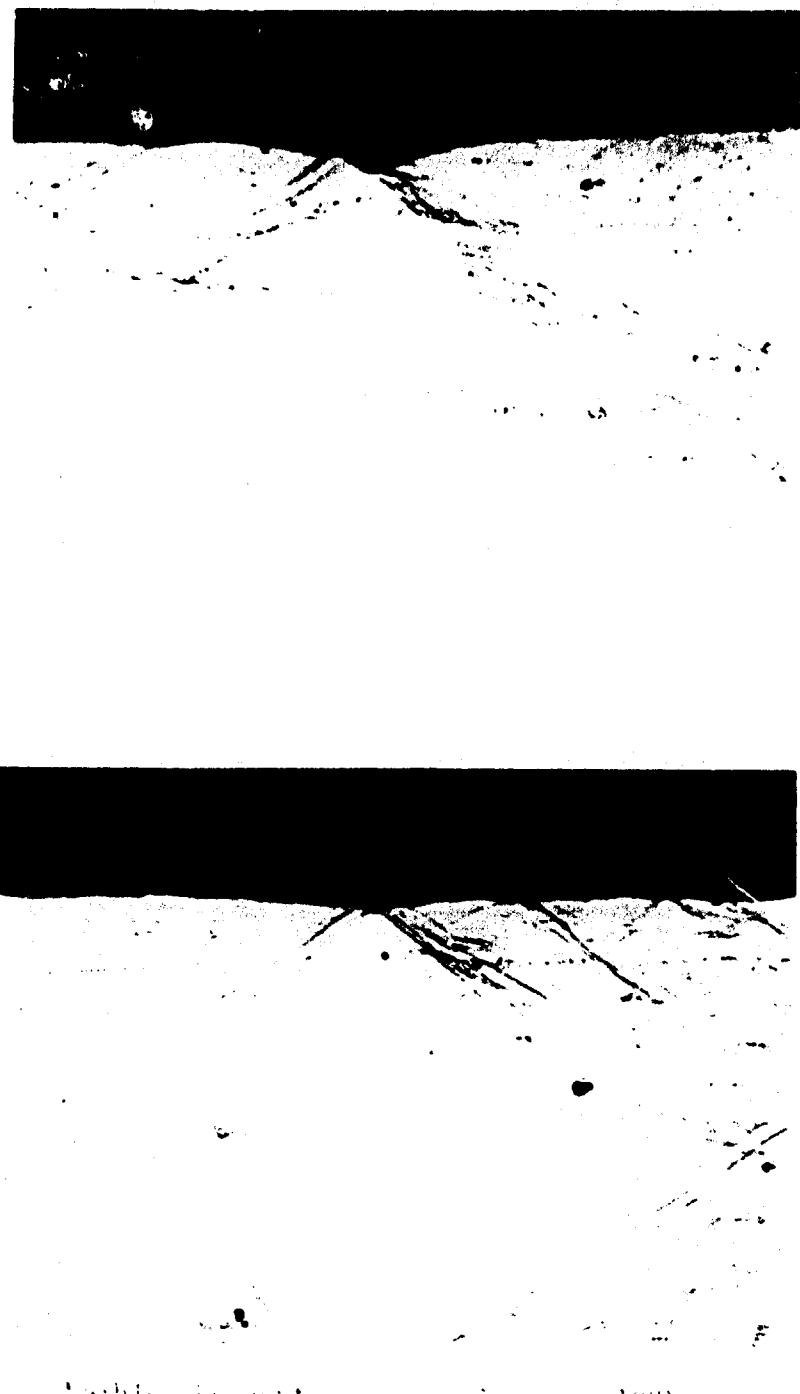
FIGURE 1A - 1/2" SCALE RULER FOR REFERENCE



Marmoleum

100V

Difficult to trap, but can be cleaned properly.

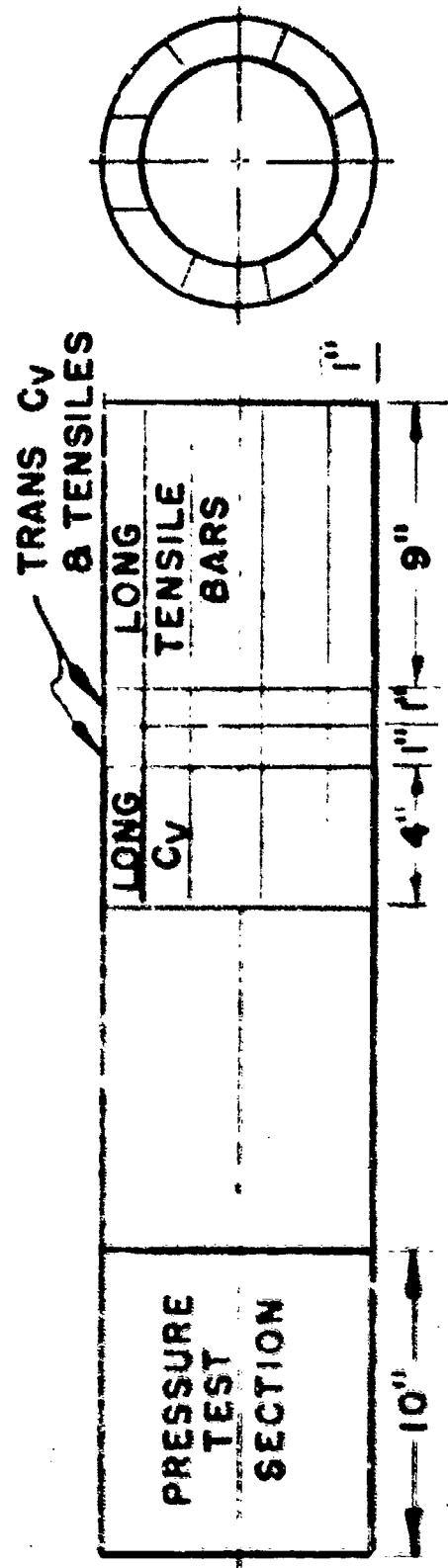


Marble Canyon

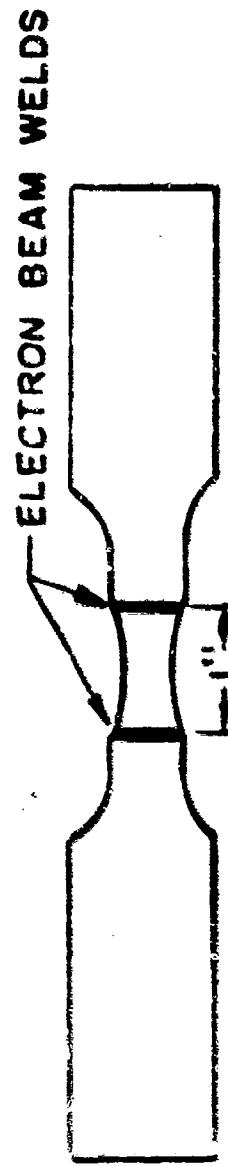
10m

100ft

500ft



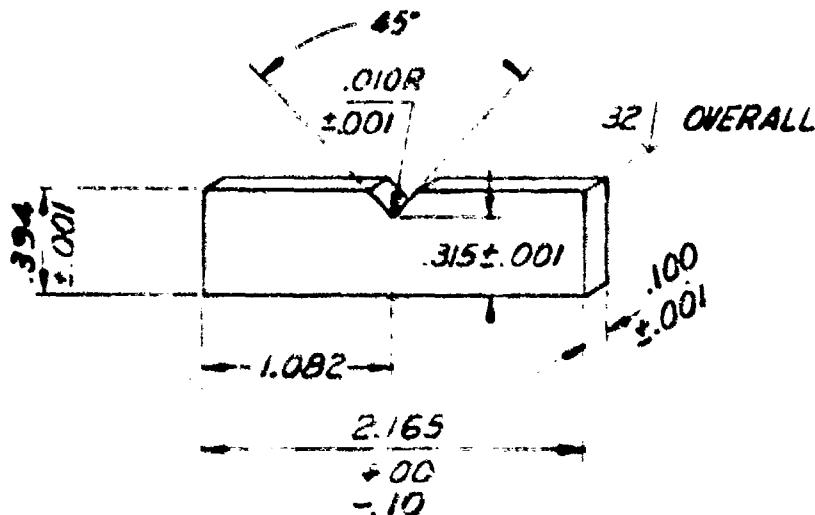
A. LOCATION TEST SPECIMENS FROM EXTRUDED & AGED TUBE



B. LOCATION TEST SPECIMENS FROM EXTRUDED & AGED TRANSVERSE TENSILE TEST SPECIMEN

FIGURE B. LOCATION OF TEST SPECIMENS  
AND EB WELDED TRANSVERSE TENSILE  
TEST SPECIMEN

SUB SIZE CHARPY



SUB SIZE TENSILE

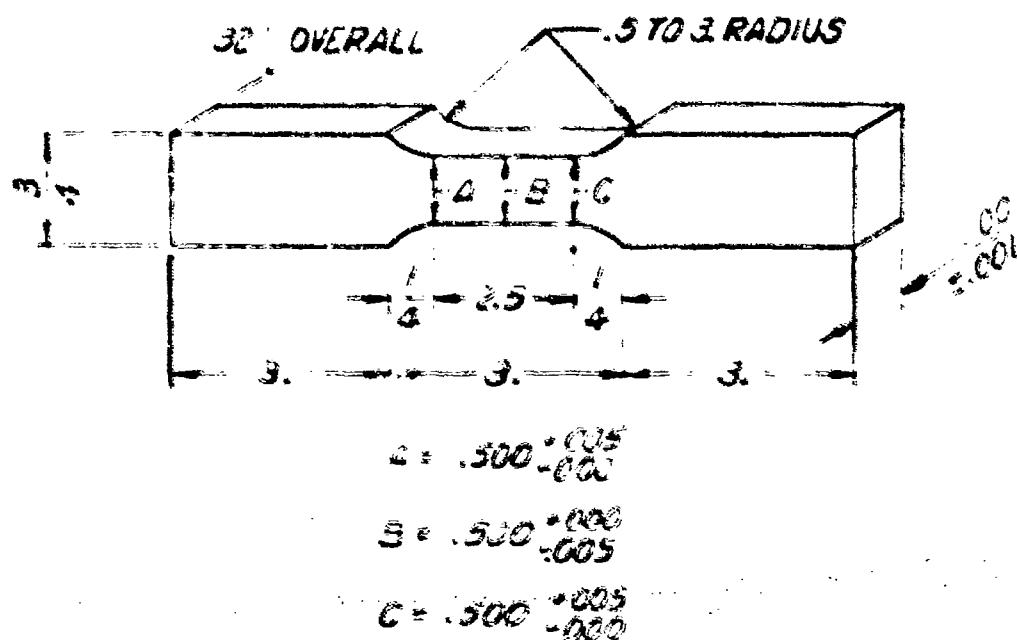


Figure 9. Subsize Charpy and Tensile Test Specimens

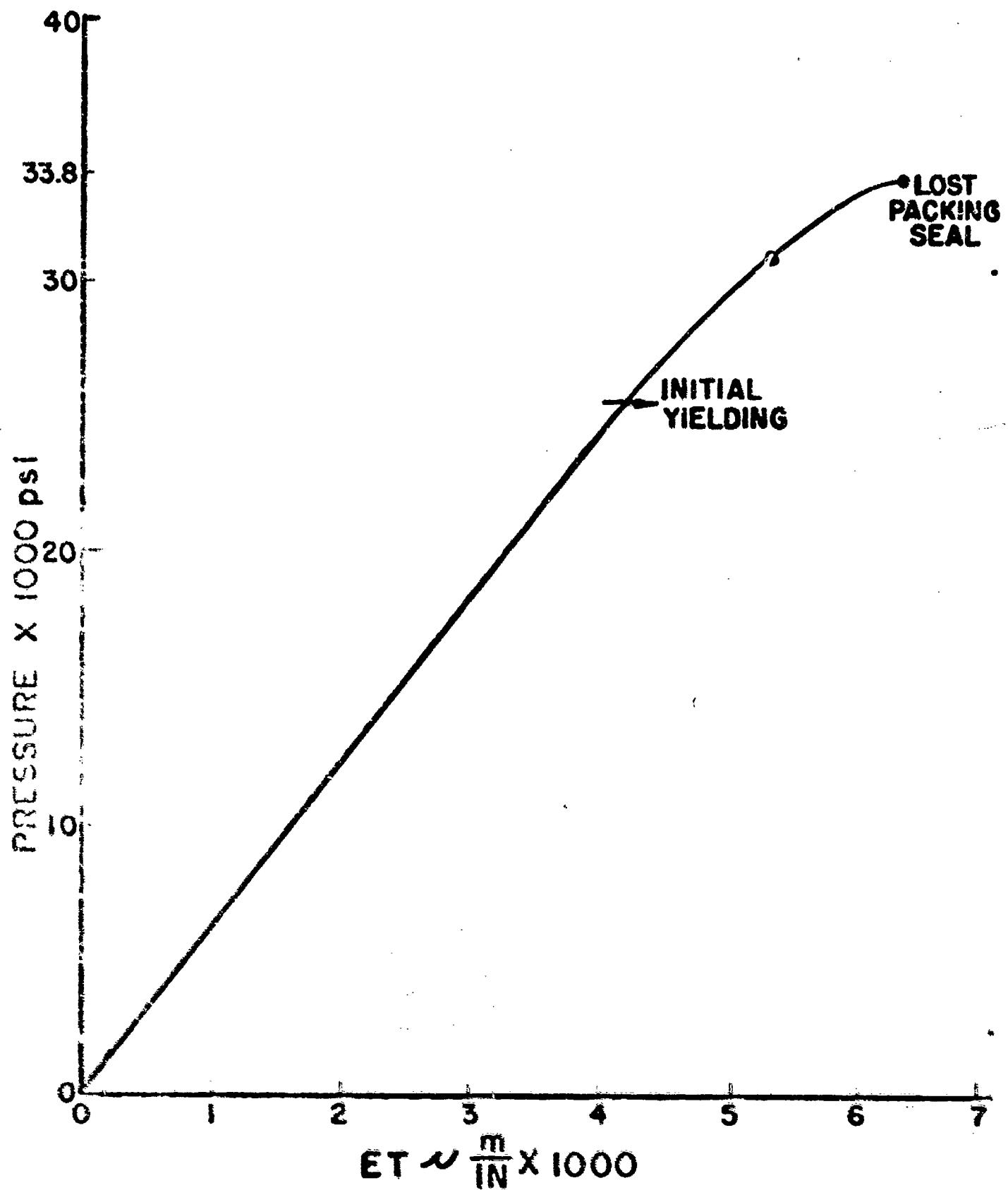


FIGURE 10 EXTRUDED 718 ALLOY TUBE PRESSURE-  
STRAIN PRESSURE TEST DATA

EXTRUDED AND MACHINED FORM TUBE



EXTRUDED AND MACHINED FORM TUBE

TABLE I DIMENSIONS AND CONCENTRICITY CHECK OF EXTRUDED TUBES

| NO. | OD        |        | ID (b) |        | WALL      |        | CONCENTRICITY |             | STRAIGHTNESS |
|-----|-----------|--------|--------|--------|-----------|--------|---------------|-------------|--------------|
|     | BREECH    | MUZZLE | BREECH | MUZZLE | THICKNESS | BREECH | MUZZLE        |             |              |
| 9   | (a) 2.761 | 2.762  | 2.364  | 2.368  | .198/.197 | 0.007  | 0.002         | 0.005/0.006 |              |
| 10  | 2.783     | 2.784  | 2.361  | 2.366  | .211/.209 | 0.005  | 0.001         | 0.008       |              |
| 11  | 2.781     | 2.784  | 2.363  | 2.367  | .209/.209 | 0.006  | 0.001         | 0.010/0.012 |              |
| 12  | 2.781     | 2.783  | 2.358  | 2.366  | .211/.212 | 0.005  | 0.001         | 0.006/0.012 |              |

All values in inches

(a) OD of this tube was centerless ground before inspection for a cost study.  
 (b) ID of tubes were honed before inspection to remove some of the taper caused by the use of a tapered mandrel.

TABLE II TENSILE PROPERTIES OF EXTRUDED AND AGED TUBE (a)

|                     | UTS   | 0.1% YS | 0.2% YS | E1  | RA    |
|---------------------|-------|---------|---------|-----|-------|
|                     | (ksi) | (ksi)   | (ksi)   | %   | (%)   |
| <u>LONGITUDINAL</u> |       |         |         |     |       |
| 243                 | 231   |         | 240     | 4.8 | 18.8  |
| 250                 | 242   |         | 247     | 3.0 | 15.0  |
| <u>TRANSVERSE</u>   |       |         |         |     |       |
| 231                 | 201   |         | 209     | 2.0 | - (b) |
| 232                 | 190   |         | 208     | 6.5 | - (b) |

TABLE III EXTRUDED 718 ALLOY PRESSURE TEST DATA

|                  |           |           |
|------------------|-----------|-----------|
| Initial Yielding | - - - - - | 25.5 ksi  |
| Packing Loss     | - - - - - | 33.8 ksi  |
| Material 0.1% YS | - - - - - | 225.3 ksi |

(Computed on the basis of 33.8 ksi internal pressure)

\*Failed in the electron beam welded area

TABLE IV V-NOTCH CHARPY IMPACT PROPERTIES(c) OF EXTRUDED AND AGED TUBES

|              | <u>Room Temp - (ft-lbs)</u> |            | <u>-40°F</u> |            |
|--------------|-----------------------------|------------|--------------|------------|
| Longitudinal | 5.2                         | (23.3)     | 5.1          | (26.0) (d) |
|              | 4.8                         | (21.6)     | 5.0          | (22.6)     |
|              | 4.6                         | (20.4)     | 4.8          | (21.6)     |
| Transverse   | 4.9                         | (22.0) (d) | 3.0          | (13.5) (d) |

- (a) Flat tensile bars 0.100" thick.
- (b) Tensile bars broke in electron beam weld.
- (c) Impact bars were 0.100" thick subsize specimens.
- (d) Previous studies have shown that the standard size Charpy values are 4.5 times the subsize values.